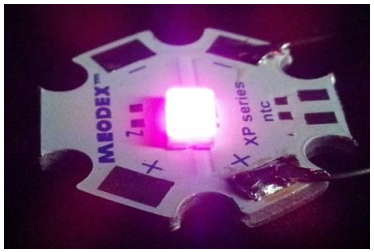
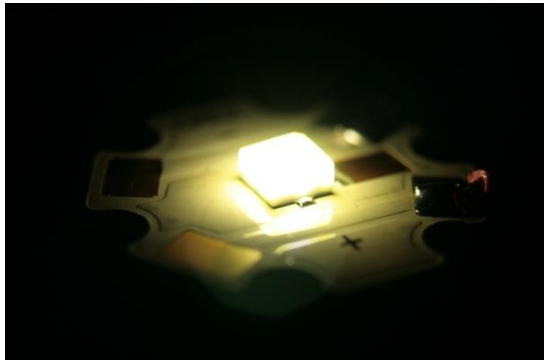
Quantum Dot Downconverters for Solid-State Lighting



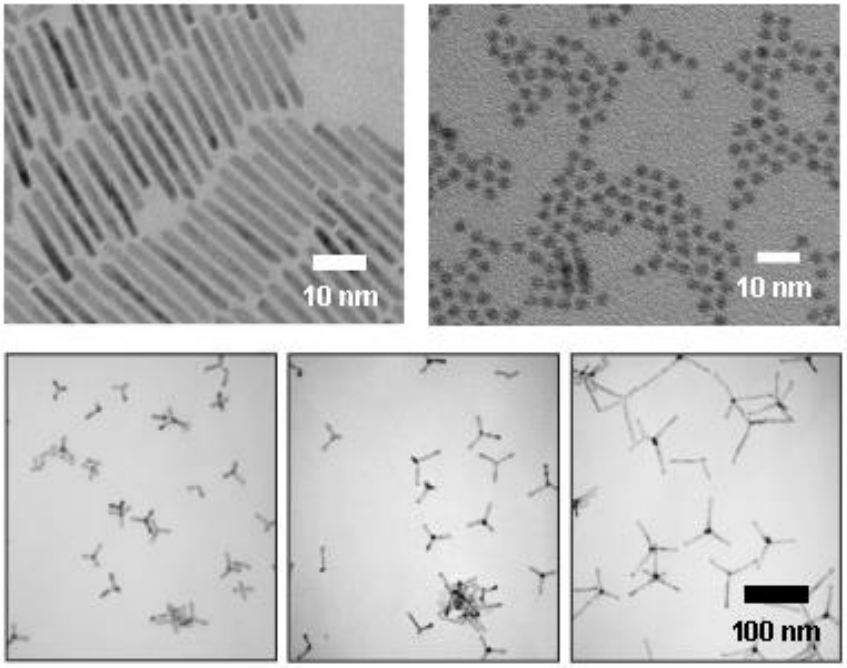


Julian Osinski, Ph.D.
VP of Product Marketing
Pacific Light Technologies

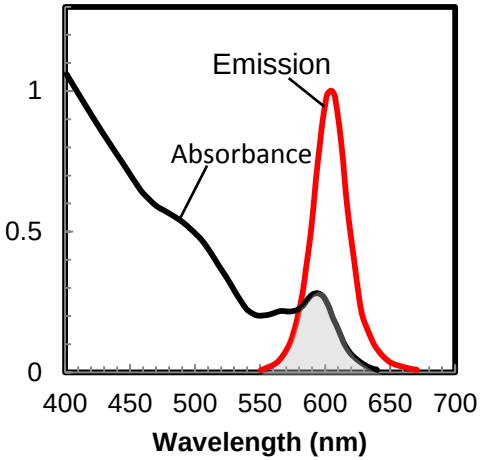
DOE SSL R&D Workshop, Tampa, FL, January 28, 2014

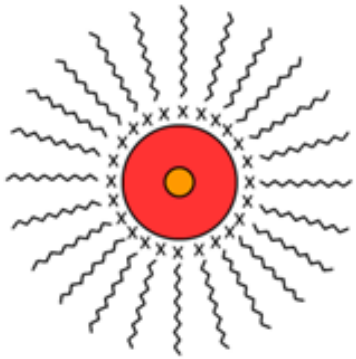
QD Nanoparticle Emitters

CdS, CdSe, CdTe



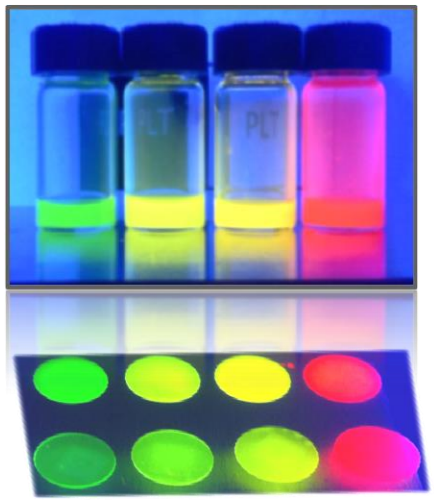
Murray, C. B.; Norris, D. J.; Bawendi, M. G. *JACS*, **1993**, 115, 8706
Alivisatos, A. P. *Nature Materials* **2003**, 2, 382

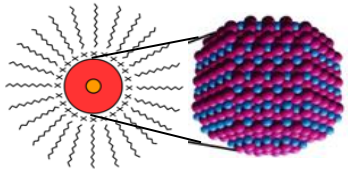


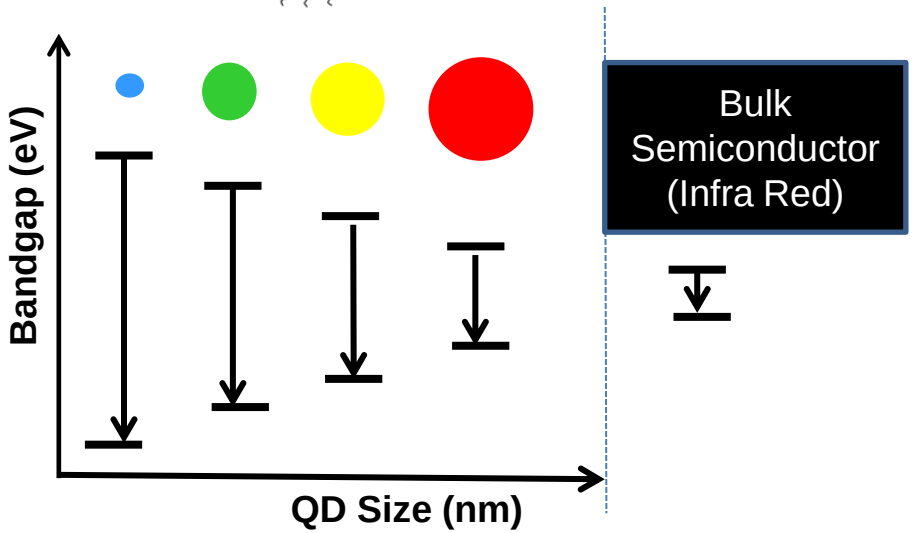


Optical properties controlled by size, materials, shape

Advantages of QD downconverters

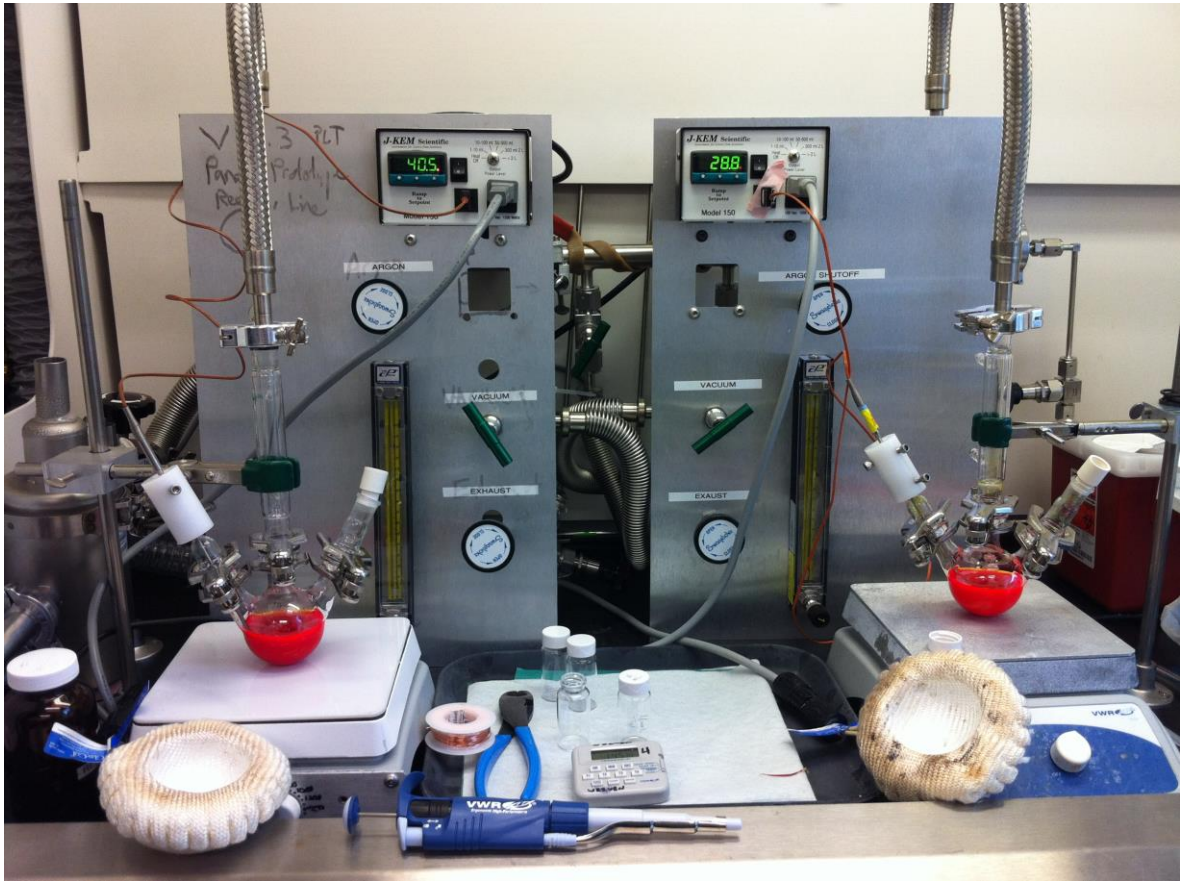






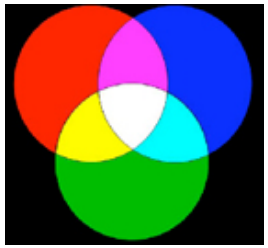
- *Precise peak emission placement (± 2 nm)*
- *Very narrow emission peaks (< 35 nm)*
- *Fast radiative decay times—(ns compared to µs)*
- *Very high efficiencies*
- *Soluble--Composites can be clear*

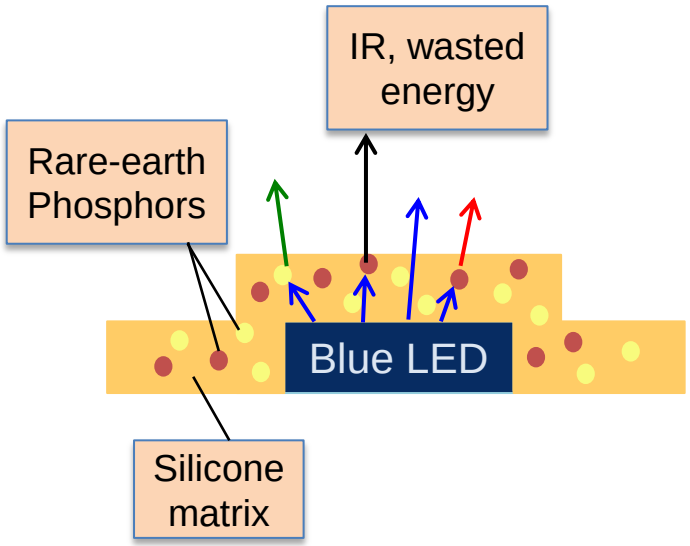
QD Synthesis

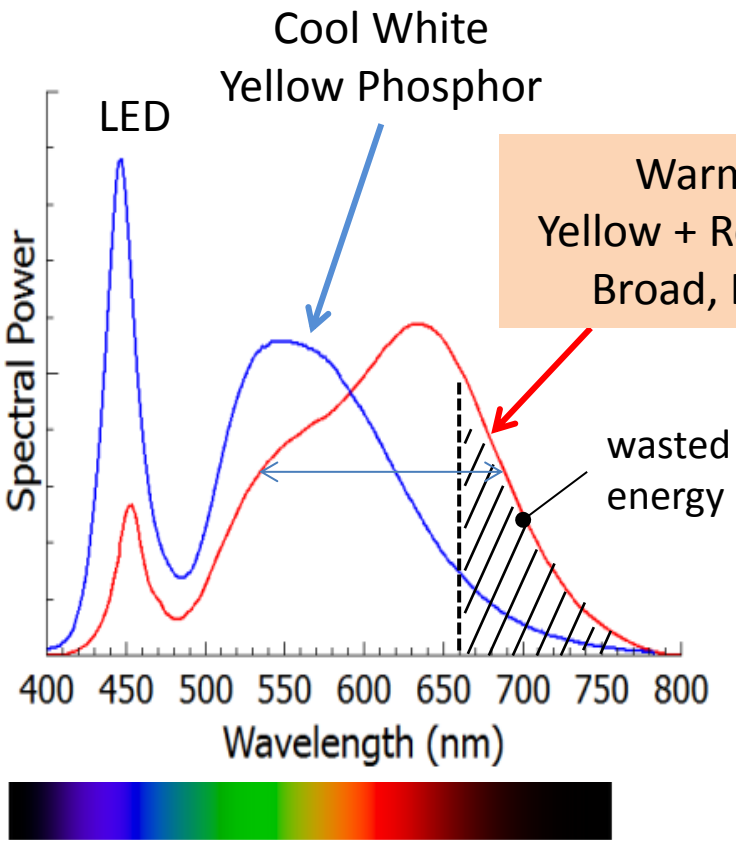


- Liquid phase inorganic chemistry synthesis process
- Low capital equipment and space requirements

White Light LEDs: How It's Done Today





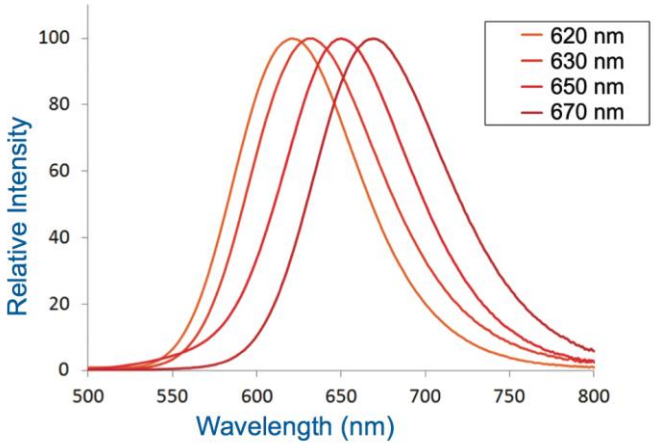


Blue LEDs + Phosphors Produce White Light

Phosphors vs QDs

Phosphors—efficient, reliable track record, but:

- Spectral widths 80-100nm typically
- Limited choices of wavelengths
- Limited absorption bands
- Contains rare-earth elements
- IP licensing requirements



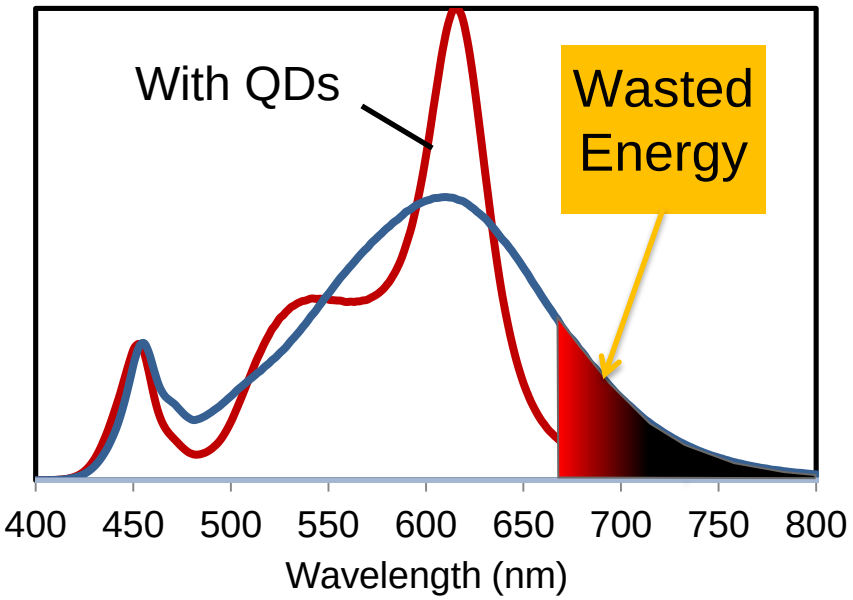
Source: Intematix

Previous QD Challenges:

- Compatibility with silicones
- Sensitivity to moisture
- Sensitivity to high optical intensity/temperature
- QD self absorption
- High cost, especially for large area remote systems
- Cd-containing materials

Why QDs in LEDs?

QDs Simultaneously Increase Efficacy and Improve Color Quality



- **Red only or multi-color wavelengths where you want them**
- **Efficacy Improvements due to narrow spectrum: less wasted energy, 20-40% benefit**
- **Customizable spectrum allows improved CRI: >90 easily obtained**

<u>QDs Reduce System Cost</u>

- Fewer LEDs required in a luminaire
- Smaller drivers and heatsinks required

Efficiency Benefits

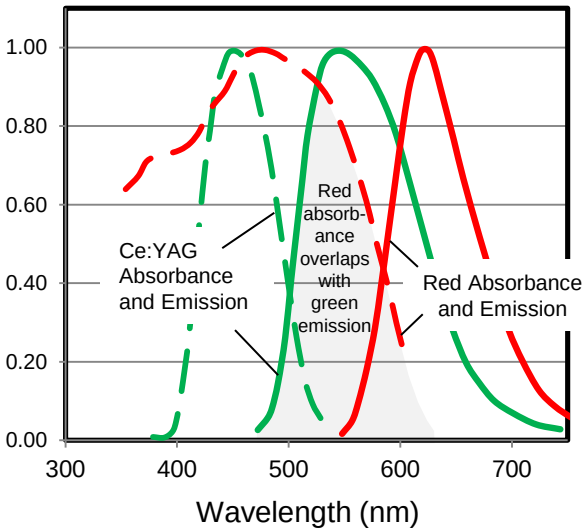
- Spectral efficiency benefits measured in Luminous Efficacy of Radiation (LER, lumens/optical watt)
- Luminous efficacy scales with LER at same quantum yield
- At downconverter quantum yield parity and cost parity, LER improvements translate directly to $/lum savings
- For a high quality of light*, this benefit can be >40%.*

	LER (lumen/optical watt)		CCT = 3000K
	Phosphor Solution	**QD Solution**	**Benefit**
CRI = 80	300	370	>20%
CRI = 95	250	360	>40%

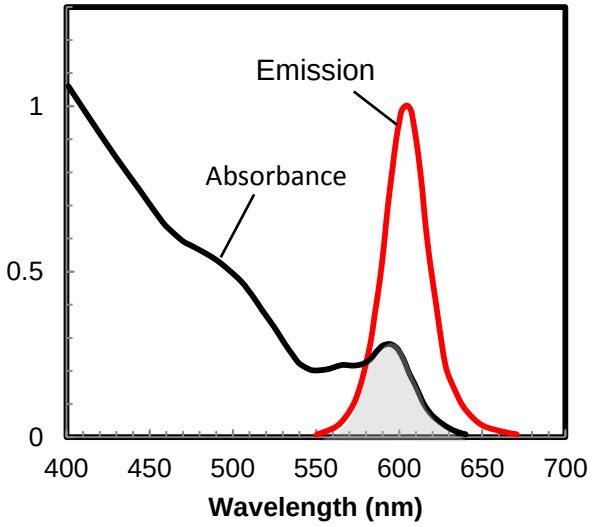
Nominal lum/$ increase

The Need for Low Self-Absorption Losses

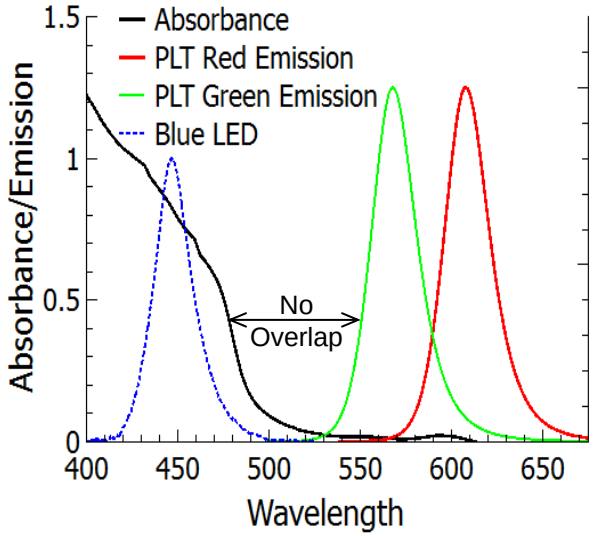
Conventional Phosphors



Conventional Quantum Dots



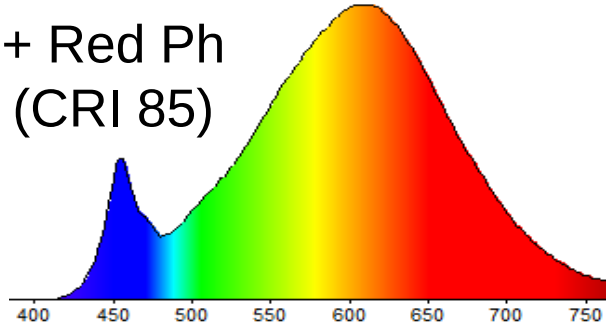
PLT Quantum Dots



Elimination of self-absorption allows high concentrations and color combinations which are difficult to achieve with conventional phosphors and conventional QDs

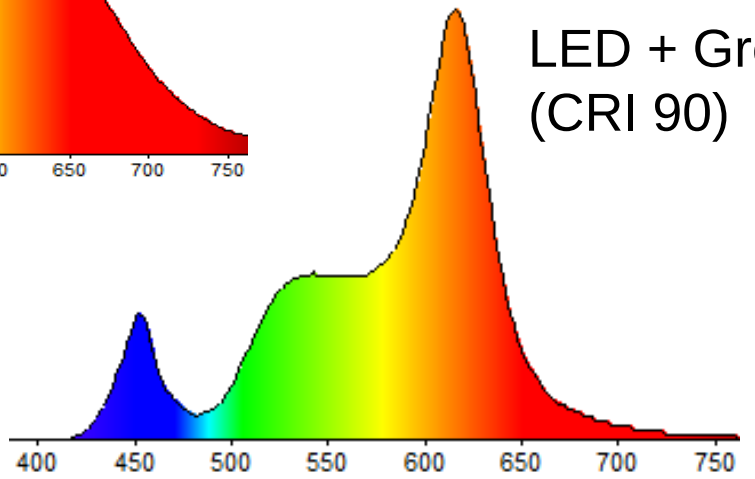
Quantum Dots Allow Maximum Spectral Engineering Capability

LED + Green Ph
+ Red Ph
(CRI 85)

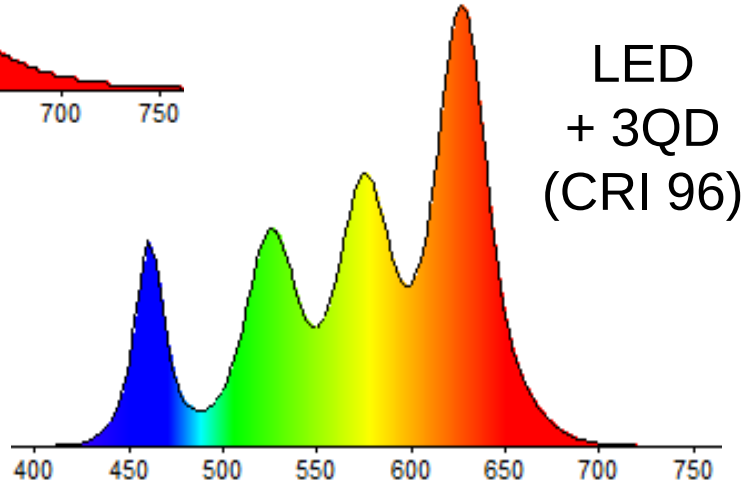


CCT = 3000K

LED + Green Ph + Red QD
(CRI 90)

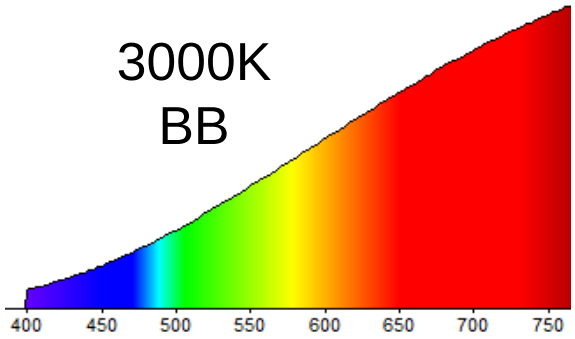


LED
+ 3QD
(CRI 96)

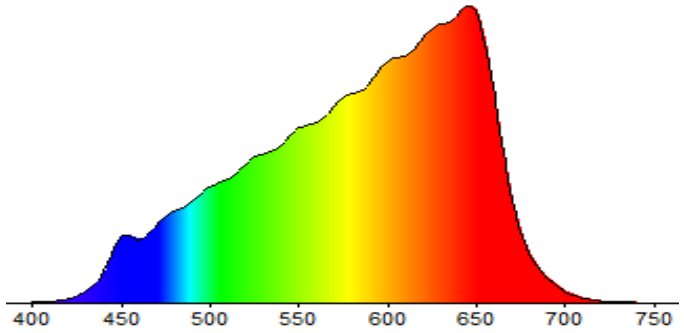


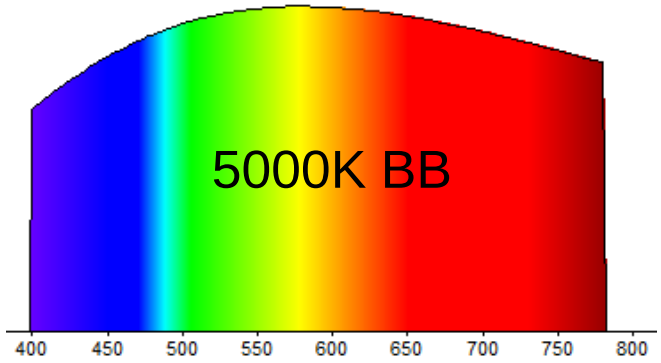
Create your own spectrum with QDs

Quantum Dots …***Color where you want it***

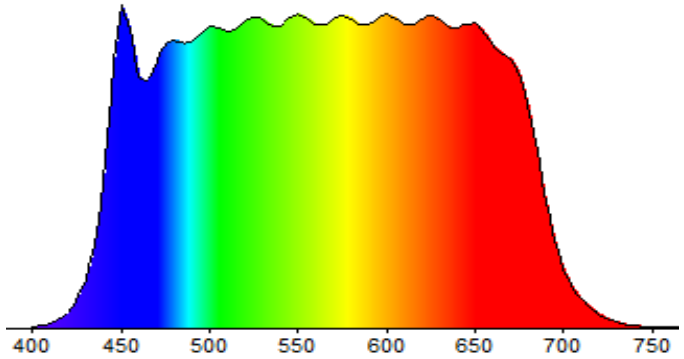


MQD





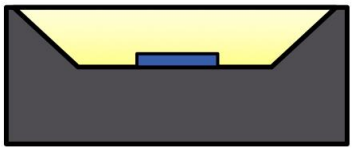
MQD



- Virtually any spectral shape, CCT, or CRI can be made
- Only achievable using QDs with low self-absorption

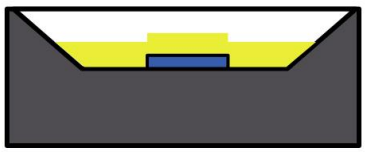
QDs in LED Packages

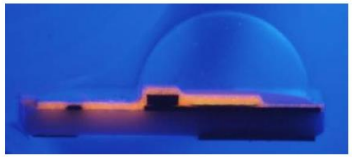
Dispersion:



Dispersed Phosphor (Cree)

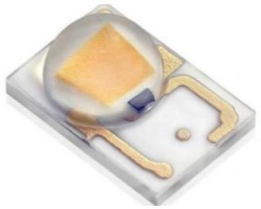
Conformal Coating Package level:





Conformal coating on a Luxeon Rebel by Philips Lumileds. The phosphor coating is visible under UV light

Conformal Coating or Pre-Form – Chip only:



Amber emission with a ceramic nitride phosphor attached to a blue die (Philips Lumileds)

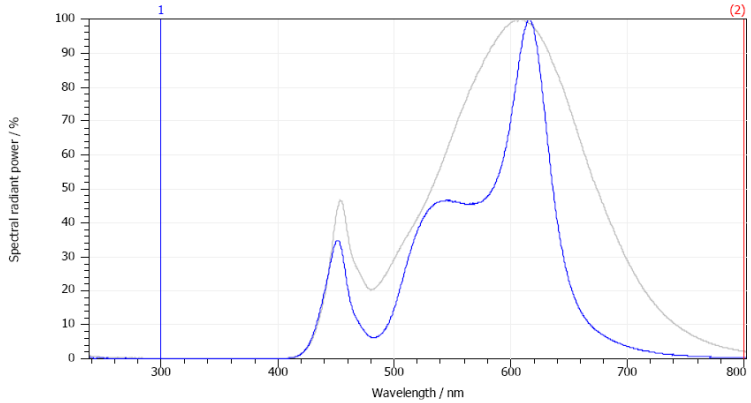
Remote Phosphor:

High Power LED with remote phosphor dome (Source: GE)

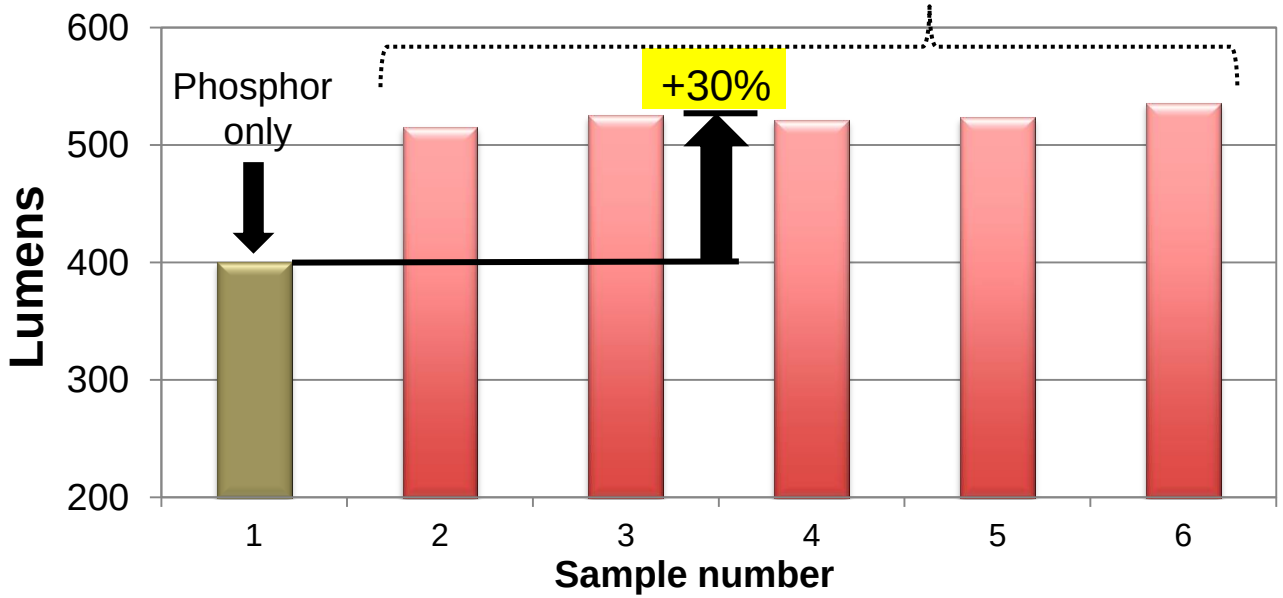
Source: Yole

Quantum dots must perform on-chip to contribute significantly to solid-state lighting

Example: 30% Efficacy Benefit



Red Phosphor replaced with QDs



CCT
~ 3000 +/- 300K

CRI
~ 88 +/- 1

A19 Lamp Case Study: Reduced System Costs

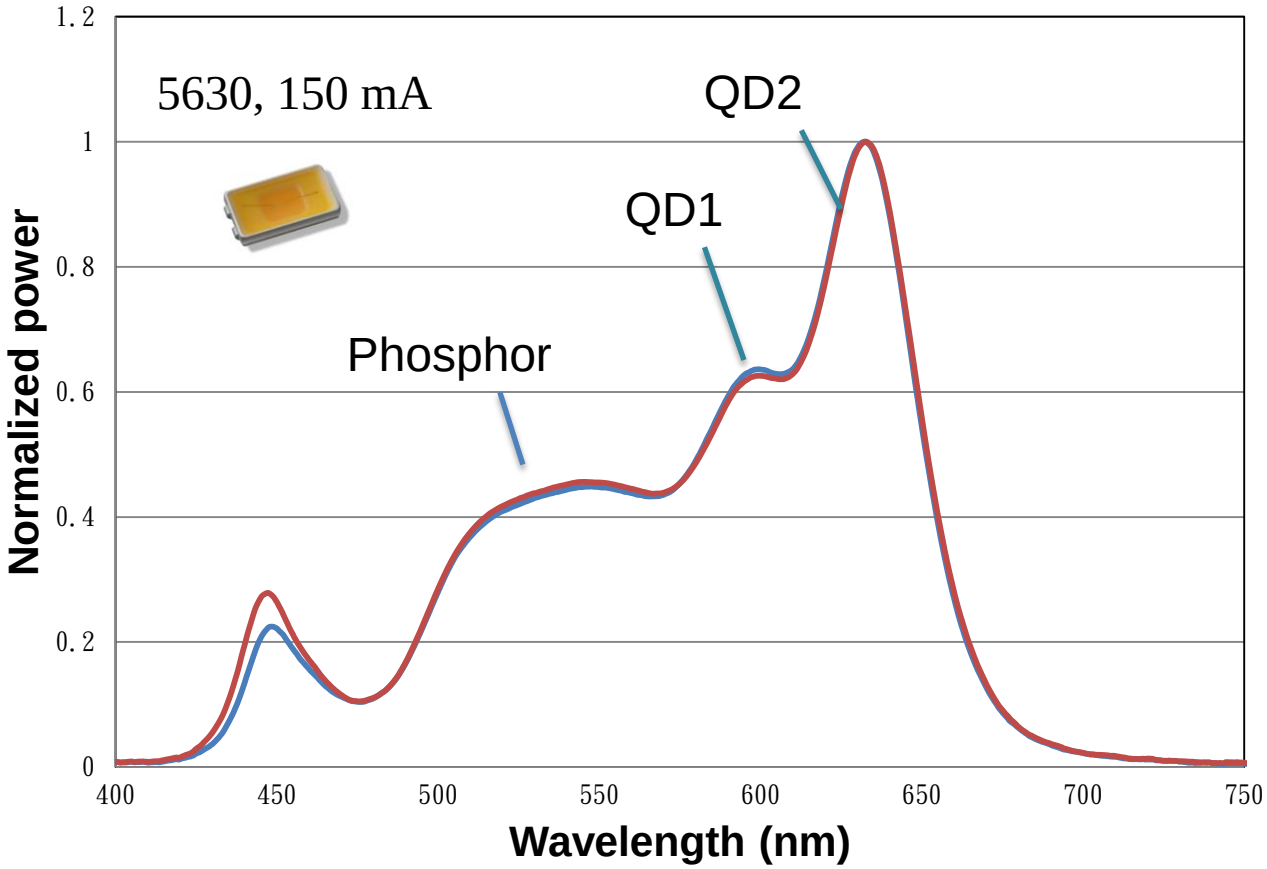
- For 3000K, 90 CRI, 30% efficacy increase from a package means:
  - 30% higher lm/W and lm/$
  - 23% lower driver costs
  - 23% lower heatsink costs
  - No additional control electronics needed, as for adding red LEDs
- A19 BOM:

800 lm LED Lamp BOM					
	conventional	with QDs			
	8 x 130 lm	6 x 167 lm			
LEDs	$ 2.16	$ 1.68	22%	savings	
Power supply	$ 1.53	$ 1.18	23%	savings	
Heat sink	$ 0.94	$ 0.72	23%	savings	
Driver	$ 0.66	$ 0.51	23%	savings	
Optic	$ 0.45	$ 0.45			
Other	$ 0.54	$ 0.54			
Tot	$ 6.28	$ 5.08	19%	lamp savings	
		$ 1.20	$ 1.20	tot savings	

Small LED premium gives 19% lamp cost reduction

High CRI using Phosphor + 2QDs

CRI = 96



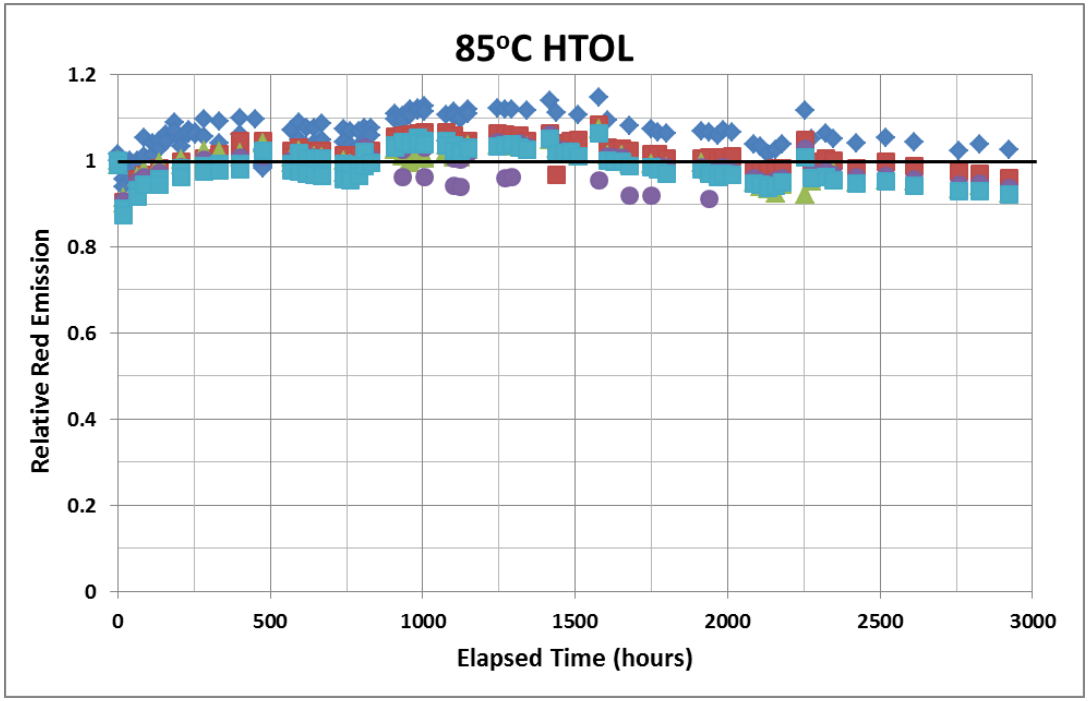
Key QD Operational Issues

- Thermal quenching
  - How much does efficiency decrease with temperature?
  - Color shift, lumen depreciation can result
  - Need this as flat as possible to 120C+

- Optical flux intensity effects
  - Blue pump power exceeds 100 W/cm2 in high power packages
  - Must sustain operational flux density at high efficiency

See Wednesday panel for data and additional information!

Recent on-chip reliability results



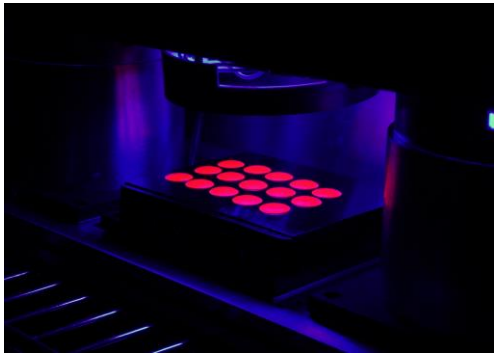
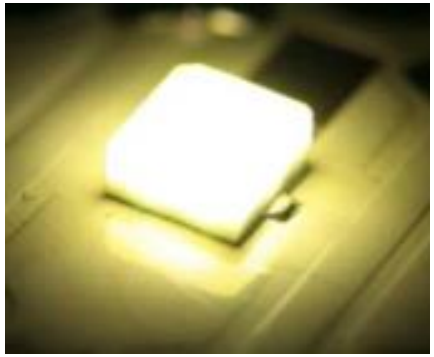
- Type 5630 packages
- 85C ambient, QDs>100C
- Flux intensity ~50W/cm2
- *Stable to >3000 hrs*

Current/Future QD Directions

- QDs tailored for on-chip applications
  - Mid-power; 50W/cm2, >120C at downconverter
  - High-power; 150W/cm2, >150C at downconverter
- Wavelengths across the spectrum
- More materials work
  - Cd-free QDs

About PLT

- HQ in Portland, OR
- Founded May, 2011
- Founders and original IP from SpectraWatt
- 35 employees/consultants
- *On-chip quantum dots – the preferred solution*

Thank you!

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Acknowledgements: Drs. Juanita Kurtin, Norbert Puetz, and the entire staff of Pacific Light Technologies